

The Galaxy–Absorber Cross-Correlation Function

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Abstract. We describe an analysis of the galaxy–absorber cross-correlation function $\xi_{\text{ga}}(v, \rho)$ as a function of velocity separation v , impact parameter separation ρ , and absorber Ly α equivalent width W on impact parameter scales that extend up to $\approx 1 h^{-1}$ Mpc.

1 Introduction

A primary goal of our imaging and spectroscopic survey of faint galaxies in fields of Hubble Space Telescope (HST) spectroscopic target QSOs (e.g. [3]) is to determine the gaseous extent of galaxies and the origin of Ly α absorption systems by directly comparing redshifts of galaxies and absorbers identified along common lines of sight. As the fundamental statistical measure of the association between galaxies and absorbers, the galaxy–absorber cross-correlation function bears on this goal for important practical and theoretical reasons. From a practical perspective, the galaxy–absorber cross-correlation function establishes the criterion by which galaxy–absorber pairs are to be assigned, while from a theoretical perspective, the galaxy–absorber cross-correlation function constrains the nature of the relationship between galaxies and absorbers.

Here we describe an analysis of the galaxy–absorber cross-correlation function as a function of velocity separation v , impact parameter separation ρ , and absorber Ly α equivalent width W . Full results of the analysis are described by [4]. A dimensionless Hubble constant $h = H_0/(100 \text{ km s}^{-1} \text{ Mpc}^{-1})$ and a deceleration parameter $q_0 = 0.5$ are adopted throughout.

2 Theoretical Expectations

It is easy to show ([4]) that if there exists a one-to-one correspondence between at least some galaxies and some absorbers then the relationship between the galaxy–absorber cross-correlation function and the galaxy–galaxy

auto-correlation function is

$$\xi_{ga}(v, \rho) = \frac{H_0}{m_a} \phi(v, \rho) + f \xi_{gg}(v, \rho), \quad (1)$$

where m_a is the absorber number density per unit length, $\phi(v, \rho)$ is the “galaxy function” or the probability of finding an absorber that arises in a given galaxy within dv , f is the fraction of absorbers that arise in galaxies, and $\xi_{gg}(v, \rho)$ is the galaxy–galaxy autocorrelation function. Although equation (1) applies *only in the absence of absorption line blending*, it nevertheless serves to illustrate general results. A more complicated expression motivated by results of numerical simulations of the effects of absorption line blending must be applied to determine the actual relationship between $\xi_{ga}(v, \rho)$ and $\xi_{gg}(v, \rho)$.

The most important implications of equation (1) are as follows: (1) The component of $\xi_{ga}(v, \rho)$ related to $\phi(v, \rho)$ exhibits an explicit dependence on m_a . Because m_a is known to vary as an exponential function of Ly α equivalent width W , the component of $\xi_{ga}(v, \rho)$ related to $\phi(v, \rho)$ is expected to vary as an exponential function of W . (2) At large impact parameter separations, where $\xi_{gg}(v, \rho) \gg \phi(v, \rho)$, comparison of $\xi_{ga}(v, \rho)$ and $\xi_{gg}(v, \rho)$ directly yields f . In practice, however, it is crucial that the effects of absorption line blending are properly modeled and accounted for in order to determine a meaningful estimate of f .

3 Observational Material

In summary, the observations consist of (1) optical images and spectroscopy of objects in the fields of the QSOs, obtained with various telescopes and from the literature, and (2) ultraviolet spectroscopy of the QSOs, obtained with the HST using the FOS and accessed through the HST archive. The optical images and spectroscopy are used to identify and measure galaxy redshifts and impact parameters. The ultraviolet spectroscopy is used to identify and measure absorber redshifts and equivalent widths.

The goal of the present analysis is to investigate galaxies and absorbers that are cosmologically intervening (rather than associated with the QSOs themselves) and absorbers that are identified on the basis of Ly α absorption lines (rather than on the basis of metal absorption lines). Hence only galaxies and Ly α -selected absorbers with velocity separations to the QSOs satisfying $v_{\text{QSO}} > 3000 \text{ km s}^{-1}$ are included into the analysis. In total, 352 galaxies and 230 absorbers toward 24 fields are included into the analysis, from which 3126 galaxy–absorber pairs are formed.

4 Analysis

The galaxy–absorber cross-correlation function $\xi_{ga}(v, \rho)$ for all absorbers (i.e. with no equivalent width threshold imposed) is shown versus velocity separa-

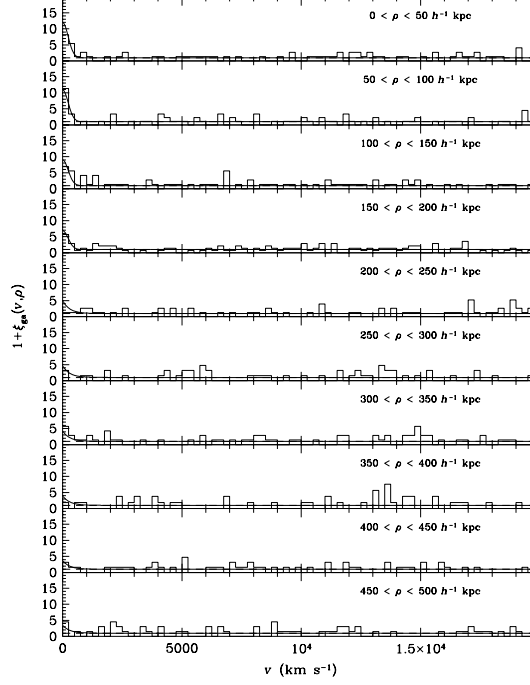


Figure 1: Galaxy-absorber cross-correlation function $\xi_{\text{ga}}(v, \rho)$ vs. velocity separation v and impact parameter separation ρ . Bin size in velocity separation is 250 km s^{-1} , and bin size in impact parameter separation is $50 h^{-1} \text{ kpc}$.

tion v and impact parameter separation ρ in Figure 1, and the galaxy-absorber cross-correlation function $\xi_{\text{ga}}(v, \rho)$ for galaxies at small impact parameters (i.e. for impact parameter separations $\rho < 200 h^{-1} \text{ kpc}$) is shown versus velocity separation v and equivalent width threshold W in Figure 2. Considering Figures 1 and 2 together with similar figures determined over different impact parameter ranges, with fits of simple models to the observations, and with measurements of the galaxy-galaxy autocorrelation function $\xi_{\text{gg}}(v, \rho)$, the following results are obtained:

- (1) Galaxies and absorbers are strongly correlated on velocity scales $v < 500 \text{ km s}^{-1}$ and impact parameter scales $\rho < 200 h^{-1} \text{ kpc}$ and are more weakly correlated on impact parameter scales that range up to at least $\approx 1 h^{-1} \text{ Mpc}$.
- (2) The amplitude of $\xi_{\text{ga}}(v, \rho)$ is significantly less than the amplitude of the galaxy-galaxy autocorrelation function on all velocity and impact parameter scales.
- (3) The amplitude of $\xi_{\text{ga}}(v, \rho)$ increases roughly exponentially with increasing Ly α equivalent width threshold on small impact parameter scales

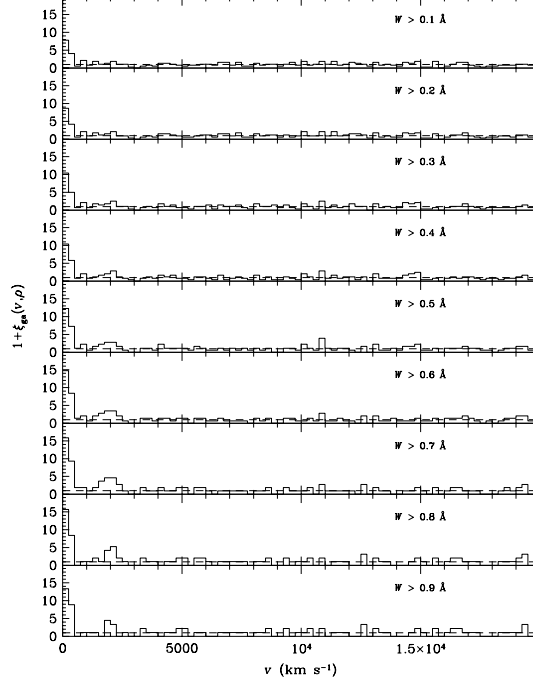


Figure 2: Galaxy-absorber cross-correlation function $\xi_{ga}(v, \rho)$ vs. velocity separation v and equivalent width threshold W for impact parameter separations $\rho < 200 h^{-1}$ kpc. Bin size in velocity separation is 250 km s^{-1} , and step size in equivalent width threshold is 0.1 \AA .

(i.e. at $\rho < 200 h^{-1}$ kpc) but is independent of $\text{Ly}\alpha$ equivalent width threshold (to within measurement error) on larger impact parameter scales (i.e. at $\rho > 200 h^{-1}$ kpc).

By combining direct measurements of the galaxy-absorber cross-correlation function $\xi_{ga}(v, \rho)$ and the galaxy-galaxy auto-correlation function $\xi_{gg}(v, \rho)$ with equations similar to equation (1) that properly account for the effects of absorption line blending, it is possible to independently estimate the galaxy function $\phi(v, \rho)$ and the fraction of absorbers that arise in galaxies f . The primary results are that (1) $\phi(v, \rho)$ extends over velocity scales $v < 500 \text{ km s}^{-1}$ and impact parameter scales $\rho < 200 h^{-1}$ kpc and (2) f is compatible with $f = 1$.

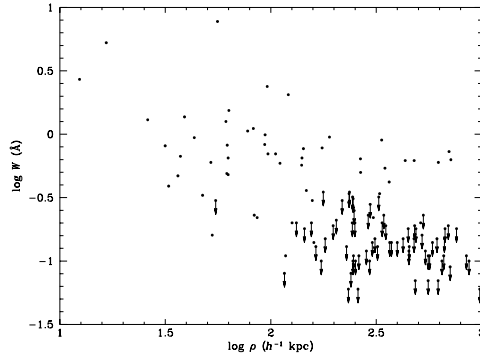


Figure 3: Logarithm of Ly α absorber equivalent width W vs. galaxy impact parameter ρ for galaxy–absorber pairs for which $\xi_{\text{ga}}(v, \rho) > 1$ (i.e. for galaxy–absorber pairs that are more likely to be physical or correlated pairs rather than random pairs).

5 Application

The most important application of $\xi_{\text{ga}}(v, \rho)$ is that it defines a criterion for statistically distinguishing physical galaxy–absorber pairs from correlated and random galaxy–absorber pairs. Physical and correlated pairs are easily distinguished from random pairs by means of the galaxy–absorber cross-correlation function $\xi_{\text{ga}}(v, \rho)$. Specifically, a galaxy and absorber pair of velocity separation v and impact parameter separation ρ is likely to be a correlated or physical pair if the cross-correlation amplitude satisfies $\xi_{\text{ga}}(v, \rho) > 1$ and is likely to be a random pair if the cross-correlation amplitude satisfies $\xi_{\text{ga}}(v, \rho) < 1$. Physical pairs are less easily distinguished from correlated pairs, because both can occur at relatively small velocity and impact parameter separations. Results of the previous section indicate the velocity and impact parameter scales over which $\phi(v, \rho)$ extends, which provides a means of distinguishing physical pairs from correlated pairs.

As an application of the practical utility of the galaxy–absorber cross-correlation function, the relationship between absorber Ly α equivalent width W and galaxy impact parameter ρ for galaxy–absorber pairs for which $\xi_{\text{ga}}(v, \rho) > 1$ (i.e. for galaxy–absorber pairs that are likely to be physically associated or correlated rather than random) is shown in Figure 3. Figure 3 demonstrates that there exists anti-correlation between absorber Ly α equivalent width and galaxy impact parameter, suggesting that the gas is directly associated with individual galaxies.

The anti-correlation between absorber Ly α equivalent width and galaxy impact parameter is explored in more detail by [1] and [2], considering the possibility of other scaling relationships with galaxy B -band luminosity, mor-

phological type, surface brightness, and redshift. The primary result of this analysis is that the gaseous extent of galaxies scales with galaxy B -band luminosity but not with galaxy morphological type, surface brightness, or redshift. This indicates that extended gas around galaxies is a common and generic feature of galaxies spanning a wide range of properties.

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